

SPACECRAFT TEST CHAMBER CONTAMINATION STUDY

AEDC MARK I FACILITY

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ABSTRACT

Recent results of a contamination study in the Arnold Engineering Development Center Mark I space simulation chamber are presented. The measurements were associated with the Global Positioning System satellite test conducted in the Mark I facility between April 6, 1977, and July 24, 1977. Multiple internal reflection spectroscopy (MIRS) internal reflection elements (IRE's), thermal control surface witness plates, and quartz crystal microbalances (QCM's) were employed to measure contaminants condensable during an extended chamber evacuation. An automatic particle counter was used to measure airborne particle density when the chamber was at atmospheric pressure. The nonvolatile residue wipe technique was employed to determine the general cleanliness of the chamber hardware. Temperature of the IRE's during chamber operation, was between 150 and 200 K. One QCM was temperature controlled to a temperature of 238 K; the other QCM operated at 135 K. After chamber repressurization, the IRE's

were scanned in the 2 to 15 μm wavelength region. Resulting spectra indicated a coating of diffusion pump fluid (DC704) at a concentration level just above the limit of detectability. The cold QCM recorded deposition during chamber evacuation. This deposit sublimed during chamber warmup at a temperature of 170 K, the sublimation temperature of water. Since neither QCM indicated a mass addition after chamber repressurization, we have used the $1.7 \times 10^{-8} \text{ g/cm}^2$ minimum detectable mass of the QCM as an upper limit for the mass of silicone fluid collected on the IRE's. This upper limit corresponds to two molecular layers of fluid for a twenty-nine-day evacuation period. The thermal control surface samples showed no change in IR spectral reflectance during the same twenty-nine-day chamber evacuation. Particle counts were taken during periods when the Mark I chamber was at atmospheric pressure. Particle densities measured for particles larger than 0.5 μm were nominally 6000 particles/ft³. Particle density for particles larger than 5.0 μm were nominally 15 particles/ft³. The airborne particle contamination in the Mark I chamber (at atmospheric pressure) was therefore below that of a class 10,000 clean room, as specified by Federal Standard 209.

1.0 INTRODUCTION

The Mark I space simulation chamber, located at the Arnold Engineering Development Center, Tullahoma, Tennessee, Fig. 1, is one of the largest facilities of its kind in the world. It measures 42 feet (12.8 meters) in diameter by 82 feet (25.6 meters) high, is constructed entirely of stainless steel and is equipped with a liquid nitrogen cooled liner over the floor, walls and portions of the ceiling to simulate the thermal environment of outer space. Eleven 32-inch (.81 meter) oil diffusion pumps form

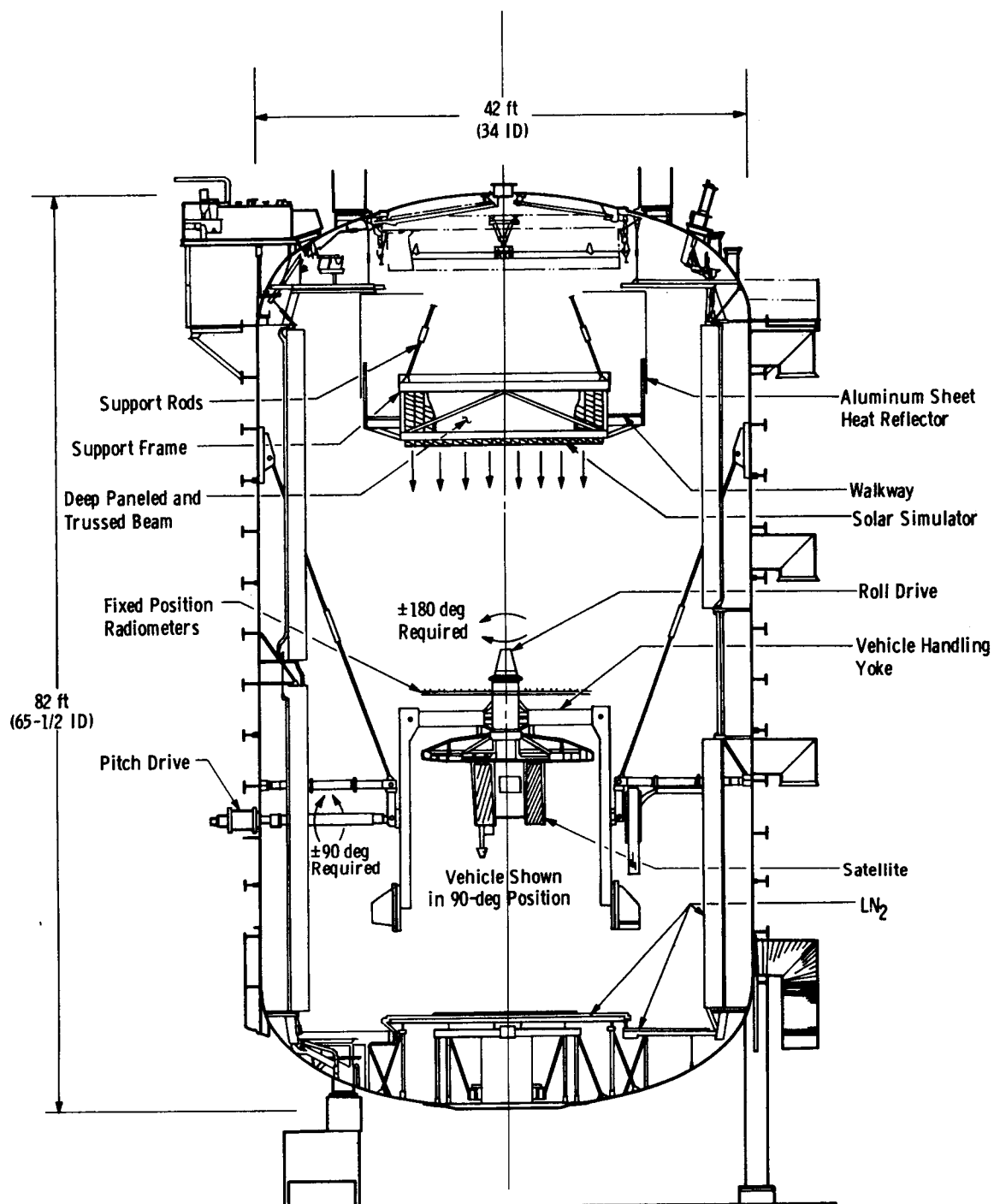


Fig. 1 Installation in Mark I Chamber

the primary pumping system and each pump has its own liquid nitrogen baffle and angle valve. This unique facility was recently employed to perform an extensive qualification test of the prototype satellite for the Global Positioning System (GPS), also referred to as the NAVSTAR system. The project is a joint effort under the Department of Defense, it is managed by SAMSO and Rockwell International is the contractor for satellite construction. When fully operational (1984) GPS will provide airborne, ship, and ground system with position information accurate to within tens of feet and velocity vectors within tenths of a ft/sec at any instant throughout the world.

Contamination of the GPS satellite during the test was of utmost concern since one of the primary objectives of the test was the verification of the thermal control system on the satellite and also a thermal mathematical model derived by Rockwell International personnel. Should contamination adversely affect the α/ϵ of the materials, conclusions from the thermal vacuum test would be ambiguous to say the least. An additional key motive for contamination measurements was the possibility of a follow-on test of a flight vehicle. Thus a contamination measurement and control program was formulated specifically for the GPS test. Since the test was unique in its duration, April 6, 1977, through July 24, 1977, and requirements, it presented an excellent opportunity to fully document the environmental conditions of the AEDC Mark I facility, a measurement not previously conducted with modern detection instruments. The threat of contamination was to be encountered during two distinct test operations, a) during installation and work periods between the space simulation tests, and b) during the actual space simulation tests. In case (a) the satellite

is subjected to particulate fallout and personnel contamination while in case (b) it is subjected to vacuum pump fluid vapors and condensible vapors outgassed from umbilical wiring and general chamber hardware. The following instruments were selected on a basis of sensitivity, applicability and availability to measure the degree of contamination originating from each of the possible sources: a particle sensing instrument, Coulter Model 550, to monitor particulate contamination levels below 10^5 per cubic foot of air (R. P. Young, ARO, Inc., was the contact engineer for particulate measurement); a nonvolatile residue (NVR) wipe test to measure surface cleanliness (E. N. Borson and L. H. Rachal, The Aerospace Corporation, were the contact engineers for the NVR measurements); a series of infrared multiple internal reflection spectroscopy (MIRS) internal reflection elements (IRE) for qualitative assessment of condensibles (J. G. Pipes was contact engineer for MIRS measurement); a series of witness plates (wafers identical in form to the satellite's outer skin) for α/ϵ measurements (J. G. Pipes was contact engineer for witness plate measurements); and finally two quartz crystal microbalances (QCM) for quantitative measurement of condensibles (D. F. Frazine was contact engineer for QCM measurements). Dr. H. E. Scott, DOTR, AEDC AF, directed and coordinated the contamination measurement program for the Air Force.

Each of the instruments is individually described below along with typical data and conclusive results, however, in general it was determined that the Mark I as a space simulation facility performed well above all expectations. The particle density for particles larger than $0.5 \mu\text{m}$ was

nominally $6000/\text{ft}^3$ and $15/\text{ft}^3$ for particles larger than $5.0 \mu\text{m}$. This is below class 10,000 as specified by Federal Standard 209; the NVR wipes showed a moderate level of surface contamination on chamber hardware; the IRE's detected only trace amounts of vacuum pump fluid; the witness samples showed no change in α/ϵ ; and the cooled QCM showed only a slight collection of water vapor.

2.0 PARTICULATE MEASUREMENTS

2.1 Instrument Description

The Mark I chamber is not equipped as a clean room. The GPS requirements of Class 340,000 are not stringent, however, and a series of particle count measurements were made near the start of test preparation to determine existing conditions. It showed that the chamber is close to the required Class 340,000 cleanliness level without special measures. Of particular importance is the fact that the chamber lid was off prior to the measurement. The addition of two room dehumidifiers, provided by Rockwell for humidity control, brought the chamber conditions within the required 340,000 class with 50% relative humidity for most of the ambient pressure periods.

In order to ensure that conditions were met around the vehicle at all times, a protective frame and surrounding cover was built for use when the vehicle was at the 0° position (antennas pointing up). The frame was attached to the vehicle lifting lug attachments. The cover was made of polyethylene with nylon mesh embedded to provide protection in event of falling objects. The vehicle was thus enclosed in an isolated volume inside the chamber.

Humidity and temperature control within the enclosed volume was maintained by a trailer mounted 15-ton air conditioning unit with attached filter furnished by Rockwell as part of the ground support equipment. This unit was located beneath the chamber and the output was ducted to the protective enclosure. A distribution manifold at the vehicle directed the output over the batteries, thermal control louvers, and SADAP drives as required. Because of the distribution manifold, these units could be cooled with or without the protective enclosure.

Particle count measurements were monitored during ambient pressure operation using a Coulter Model 550 counter; manufactured by Coulter Electronics, Inc., Hialeah, Florida. The counter employs the near-forward light scattering technique and can detect particles of size greater than $.5\mu\text{m}$. A simplified block diagram of the counter is given in Figure 2. Particles are detected and sized by collecting an air sample through a positive displacement flow system and passing the particle laden air between the light source and photoelectric detector. A resulting pulse, proportional to the particle size, is amplified and sorted by size in an amplifier card, then subsequently fed to a logic card for conversion to digital code. The digital code is displayed on the front panel and also accessible from a data card. Calibration of the counter is performed by the manufacturer using monosized particles in a range of $.5\mu\text{m}$ to $20.0\mu\text{m}$. An accurate absolute calibration accuracy for the instrument is not known. During the installation of the GPS and between-test operations the particle counter was located on the floor of the chamber since measurements under the satellite tent

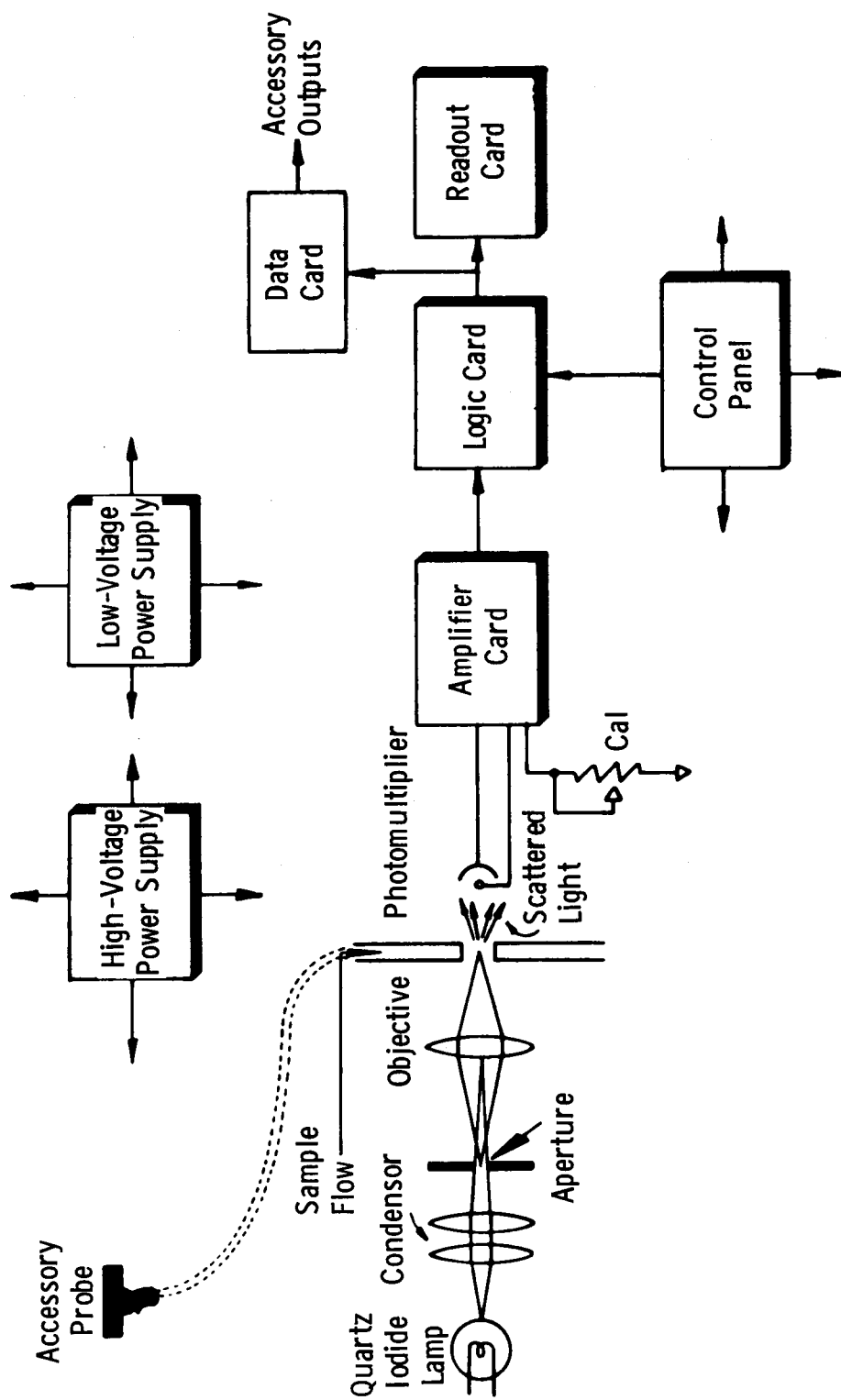


Fig. 2 Block Diagram of Particle Counter

showed no significant difference between the two locations. As would be expected the count level varied considerably depending upon the level of personnel activity in the chamber.

2.2 Typical Data and Results

Particle count data was hand recorded; see Figure 3 for a typical result during a work period of moderate activity. As is clear from Fig. 3, the particle density for sizes greater than $0.5\ \mu\text{m}$ were nominally $6000/\text{ft}^3$ and $15/\text{ft}^3$ for sizes greater than $5\ \mu\text{m}$. The Mark I can therefore be classed as 10,000 for the GPS test. It is believed that this more than adequate low count level was due to the pre-test cleaning of the chamber and test hardware, the clean room personnel procedures during installation and modification periods (all personnel wore caps, gloves, smocks and shoe covers), and the operating procedures in general.

It should be noted that a correction to the particle count was made after the test. Originally class 100,000 was reported, based on a Royce Model 245 counter. It was later found that the Royce was severely out of calibration. Following calibration the Royce agreed closely with the Coulter, thus the Coulter data reported herein is believed to be accurate.

3. NVR (Non-Volatile Residue) Measurements

3.1 Solvents and Procedures

Non-volatile residue (NVR) was measured on both the Mark I test chamber and dummy space vehicle surfaces. NVR measurements were initially performed prior to and after chamber pumpdown tests with a simulated space vehicle. No additional NVR measurements

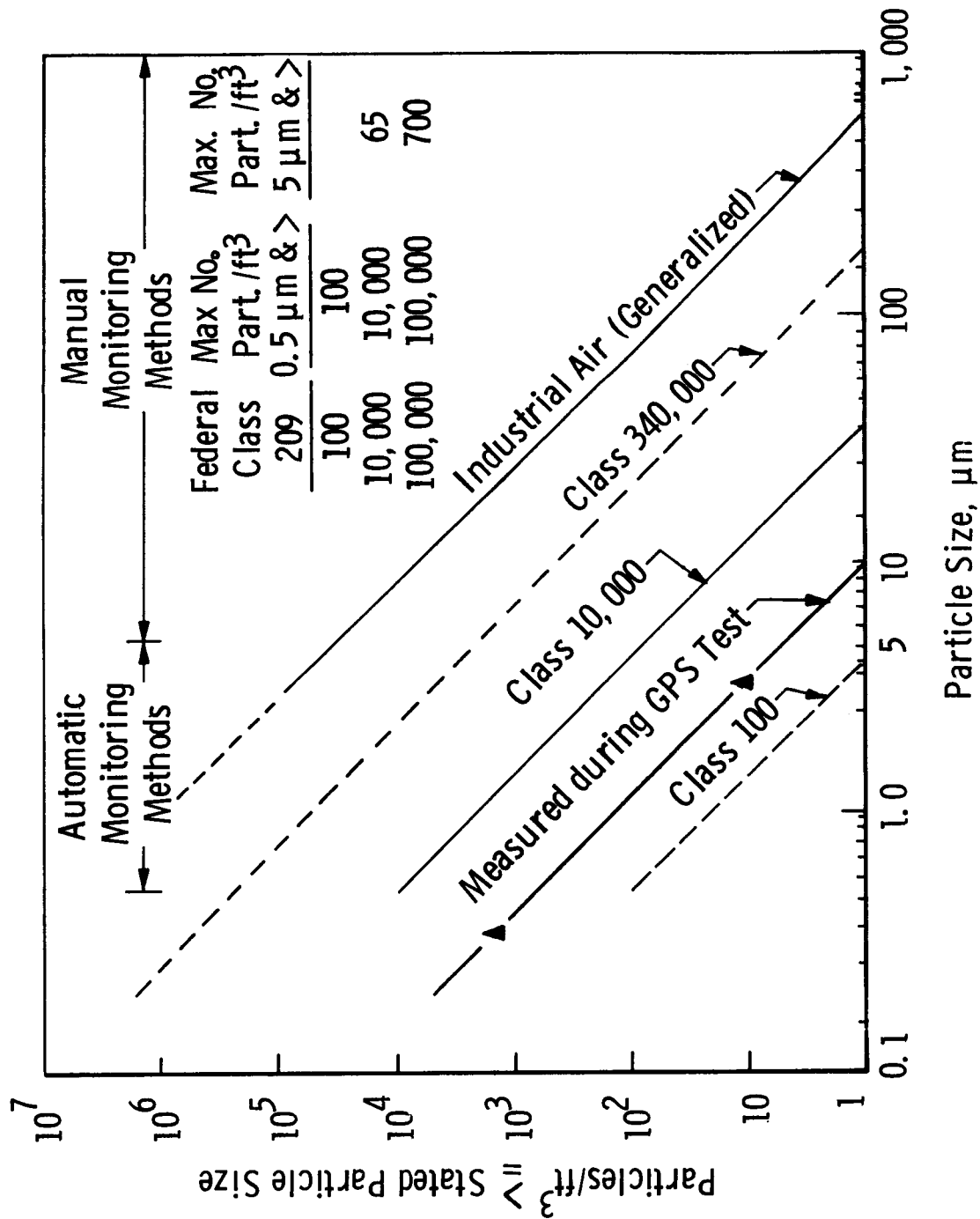


Fig. 3 Particle Size Measurement during a Work Period of Moderate Activity

were performed following the qualification test on the GPS space vehicle because the QCM's and IRE's indicated negligible NVR levels.

The NVR procedure consists of wiping the surface with a cloth dampened with a mixture of 1, 1, 1 trichloroethane and ethanol. Soxhlet of the cloths is employed to remove soluble residues, and the solvents are triple distilled to reduce the NVR to approximately 1 ppm. A solvent mixture of 75% 1, 1, 1 trichloroethane and 25% ethanol by volume is azeotropic (has a single boiling point) and is, therefore, convenient for use in Soxhlet extraction.

A surface area of approximately 0.1 m^2 (1 ft^2) is wiped with the solvent dampened cloth twice, each time with a fresh cloth. The cloths are retained in a clean sealed container until removed for the solvent extraction process. For this test, the used wiping cloths were returned to the Aerospace Corporation Ivan A. Getting Laboratories for solvent extraction and NVR determination.

The extraction process consists of removing the NVR from the cloth in an ultrasonic bath using the 75%/25% solvent mixture. The solvent is then evaporated and the NVR is weighed. The evaporation is performed at room temperature rather than at an elevated temperature such as is used in the ASTM standard test methods.

The NVR is usually retained for further analysis should such information be required. Infrared MIRS is frequently used because of the small quantities of NVR that usually are available.

3.2 NVR Results

The results of NVR measurements performed during the Mark I chamber tests are as follows for a wipe taken on a cable tray: 33 mg/m² (3.1 mg/ft²) before the warm pumpdown and 15 mg/m² (1.4 mg/ft²) after the cold pumpdown. The NVR levels were considered to be high, and additional cleaning of the Mark I chamber was performed prior to starting the qualification test. Infrared spectroscopy had shown the NVR to be primarily a lubricant used on the test fixture.

4.0 MIRS MEASUREMENTS

4.1 IRE Description and IR Spectrum

Multiple internal reflection spectroscopy (MIRS) at infrared wavelengths is one of the more sensitive techniques for qualitative identification of infrared active compounds where very low level concentrations are available. The principles of MIRS (also commonly referred to as ATR (attenuated total reflection), TIR (total internal reflection), and FTIR (frustrated total internal reflection)), as well as the instruments and applications of the technique are given by Harrick¹ in a fine text on internal reflection spectroscopy. There is also an ANSI/ASTM Standard on the subject.² Basically polychromatic radiation, in most cases infrared of the 2-25 μ m wavelengths, is directed into a prism shaped crystal so that the angle of incidence

¹Harrick, N. J., Internal Reflection Spectroscopy, John Wiley & Sons, Inc., (1967).

²ANSI/ASTM E573-76, Standard Recommended Practices for Internal Reflection Spectroscopy, American Society for Testing and Materials, Annual Book of Standards, Part 42.

at the points of internal reflection are greater than the critical angle. The radiation is totally reflected at the crystal-air interface but the electric field does penetrate the rarer medium (air), a distance not greater than a few wavelengths, and is damped exponentially. The waves that attempt to penetrate the rare medium are termed "evanescent" or "frustrated" and lead to the concept of frustrated total internal reflection. If the air (a dielectric) is replaced by a conductor, for example the condensation of a volatile contaminant onto the crystal, the evanescent waves will be attenuated, for wavelengths at which the contaminant is active, allowing absorption infrared spectroscopy to be performed. This condition leads to attenuated total reflection (ATR) which is the technique employed for contamination detection and identification during the GPS Mark I space simulation test. One other optical measurement was conducted, an IR specular reflection measurement of thermal control witness plates, which is described following the MIRS discussion.

The preceding paragraph described ATR using a prism shaped crystal, but in reality a trapezoidal-shaped crystal is employed so that multiple reflections occur, amplifying the detection sensitivity similar to a multipass transmission cell. Many geometric styles of IRE crystals have been fabricated¹, however, the trapezoidal shape is the most common commercially available configuration. For the GPS test KRS-5 single pass crystals (52.5 x 20 x 2 mm, with 45° face angles) mounted in Delrin[®] holders were employed. Three AEDC plates and four Aerospace Corporation (Mr. E. Borson was the primary contact for Aerospace Corporation) plates were mounted at

Table 1 IRE's on GPS Test

IRE I.D.	Location	Temperature*
IR-6	On GPS looking along -Y axis	Same as GPS
IR-8	On GPS looking along +Y axis	Same as GPS
IR-2	On radar tower looking down and out at cryopanel	150-to-200 K
IR-10	On radar tower looking up and out at GPS	150-to-200 K
AEDC #1	On pitch yoke looking at GPS	150-to-200 K
AEDC #2	On pitch yoke looking opposite direction as #1	150-to-200 K
AEDC #3	On pitch yoke looking at radar structure	150-to-200 K

*Thermocouples placed in reference ovens and referenced to other reference ovens.

**Thermocouples shorted at data system path panel.

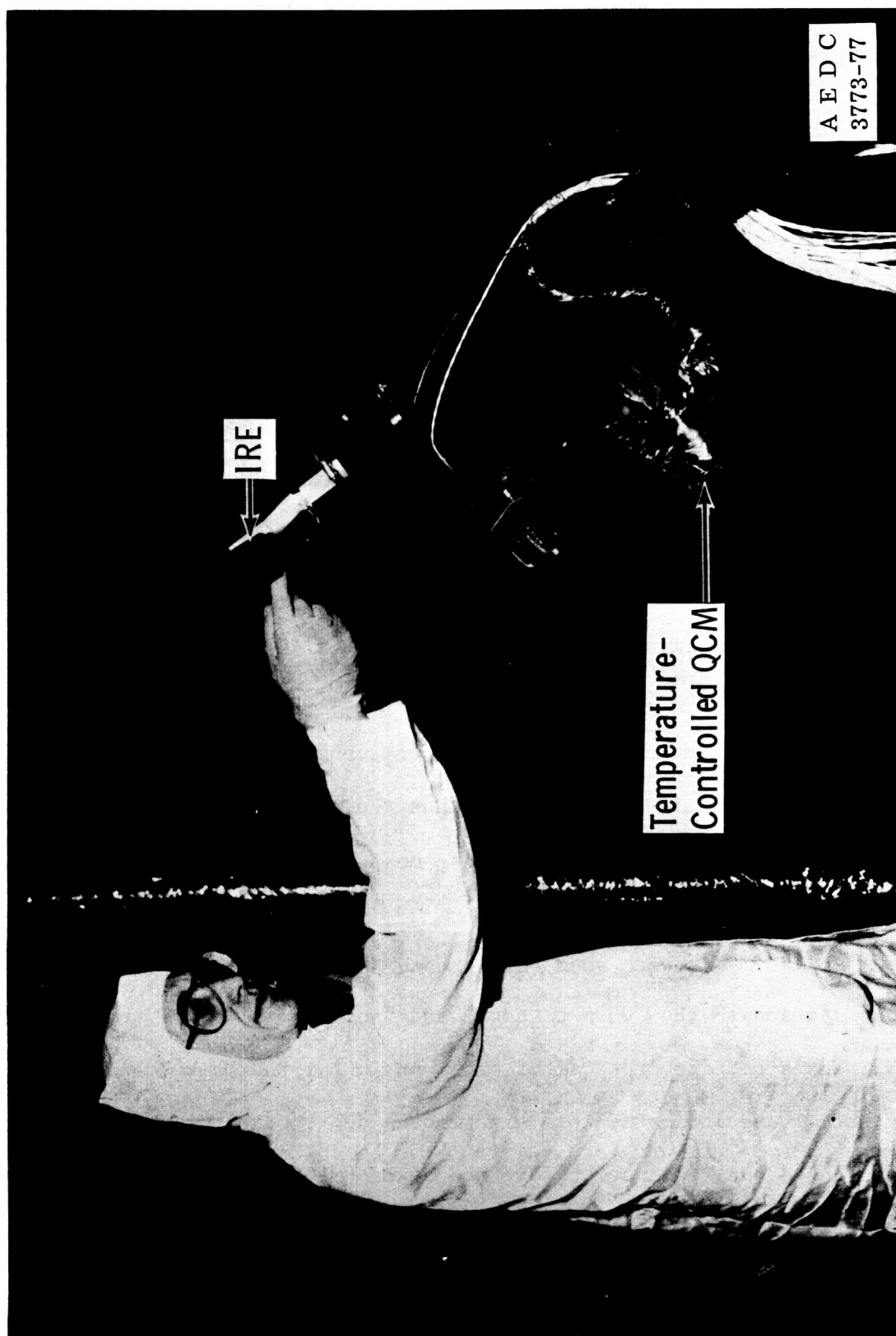


Fig. 4 Photograph of IRE and Temperature-Controlled QCM

locations outlined in Table 1. The temperature history of each plate is also indicated in this table. The KRS-5 IRE's were purchased from Wilks, Norwalk, Connecticut. One IRE and the QCM's are shown in Fig. 4. During the entire course of the test all MIRS spectra were obtained using the Wilks Model 9 internal reflection attachment and the Perkin-Elmer Model 21 double beam spectrophotometer, located at the AFDC Chemistry Laboratory. The Model 21 has a sodium chloride prism which resulted in a nominal spectral resolution of 1% for the slit program used for wavelengths between 2.0 and 15.0 μ m.

All of the IRE's were scanned prior to installation for a baseline or background spectrum. In general, all of the plates showed a smooth transmission spectrum rising from 40% at 2.0 μ m to 90% near 10 μ m then dropping off to 70% transmission at 15 μ m. The reference beam attenuator on the Model 21 spectrophotometer was adjusted to give the 90% transmission at 10 μ m, thus the transmission values for all MIRS data presented is a relative measurement.

4.2 Typical Results

The IRE's were used during each pumpdown-vent cycle with exception to the "warm bakeout" and "cold pumpdown" of the Mark I. Spectra were recorded after each venting of the Mark I and if contamination was indicated to a significant degree the IRE's were cleaned and rescanned before the next pumpdown. After the GPS was installed there were four pumpdowns and vents during the test sequence, i.e., 1) spin drift, 2) on-orbit #1, 3) on-orbit #2, and 4) on-orbit #3. The spin-drift test took five days after which the

IRE's were scanned for the first time after being under vacuum. A number of weak features were observed in all of the plates spectra which was not recognized as significant until after the on-orbit #1 MIRS measurements. The spectral features for IR-6 and IR-8 were interpreted as baseline fluctuations and the bands of all other plates (e.g., IR-2) were unexplained at the time (see Figs. 5 and 6). It was concluded that no contaminant was detected on the IRE's and they were reinstalled for the on-orbit #1 sequence. After the on-orbit #1 MIRS spectra were obtained (the on-orbit lasted 15 days) it became clear that the spectral features were real and a search for a matching spectrum (from the data by F. C. Gross, NASA Goddard Space Flight Center, "Infrared Characterized Spacecraft Contaminants and Related Compounds") revealed that DC-704 was identifiable. The broad weak band in the MIRS spectra at 9.4 μm is, no doubt, the 9.4 μm strong band in the DC-704 reference spectrum. The 3.5 μm , 12.5 μm , 13.75 μm and 14.4 μm absorption bands were also just identifiable in the MIRS spectra, see for example Fig. 7. IR-6 and -8 located on the GPS showed a slightly different spectrum with the 9.45 μm feature being more triangular shaped, as compared to the square 9.40 μm band shape in Fig. 7, see Fig. 8. Although it is recognized that this band could be an indication of another contaminant, it is felt that DC-704 fluid is the most probable candidate.

For the on-orbit #2 sequence the IRE's were not cleaned before installation so that a check for accumulation could be made. It was in question whether the DC-704 was deposited during the pumpdown or vent sequence or a gradual accumulation during the entire test sequence.

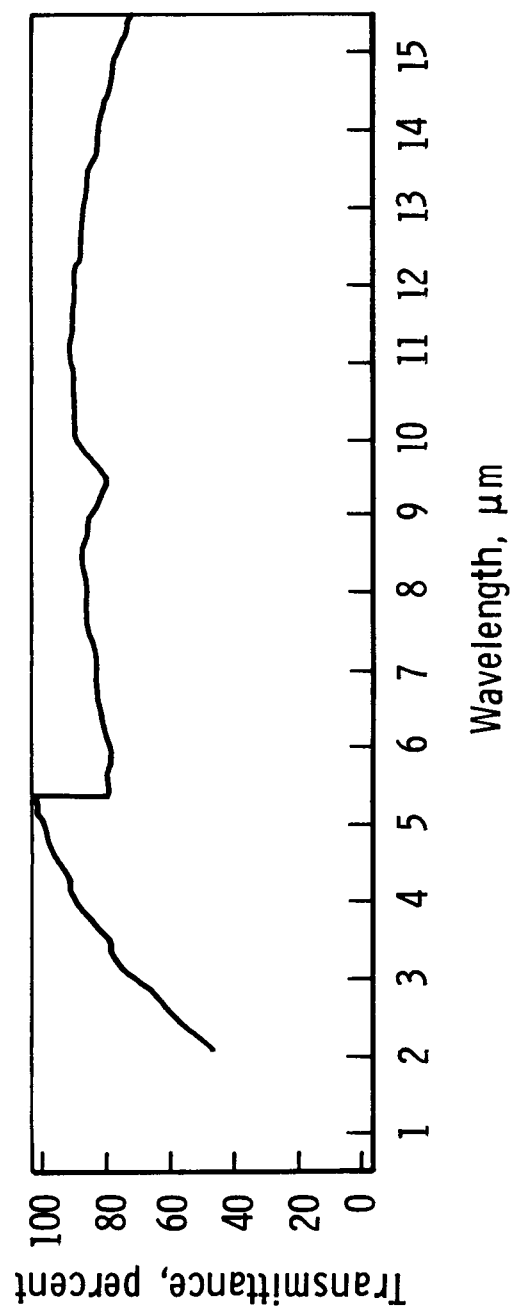


Fig. 5 IRE Spectrum--Post Spin-Drift (IR-8)

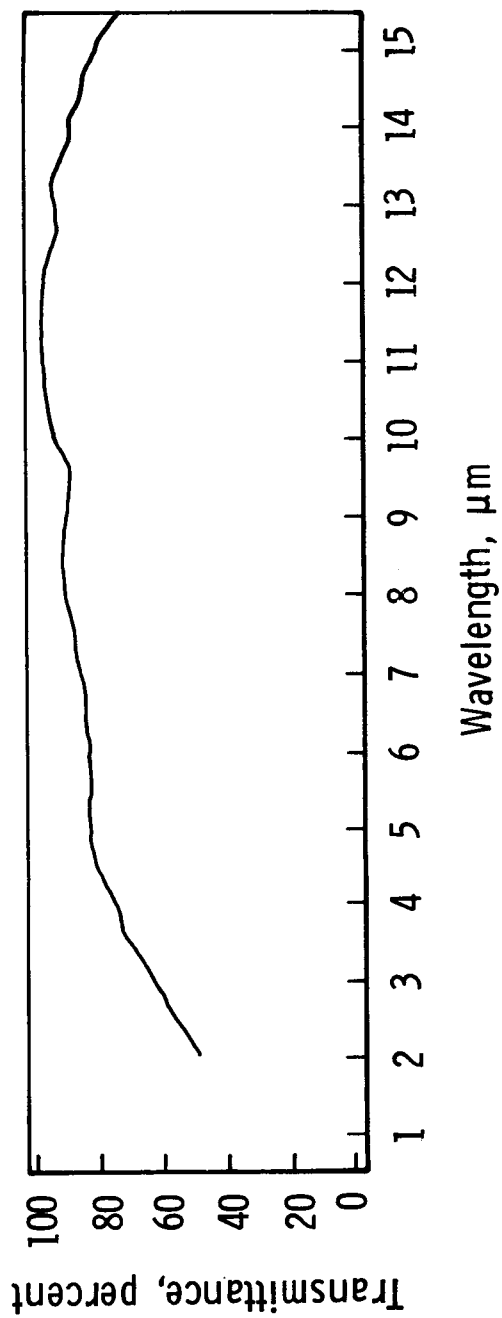


Fig. 6 IRE Spectrum--Post Spin-Drift (IR-2)

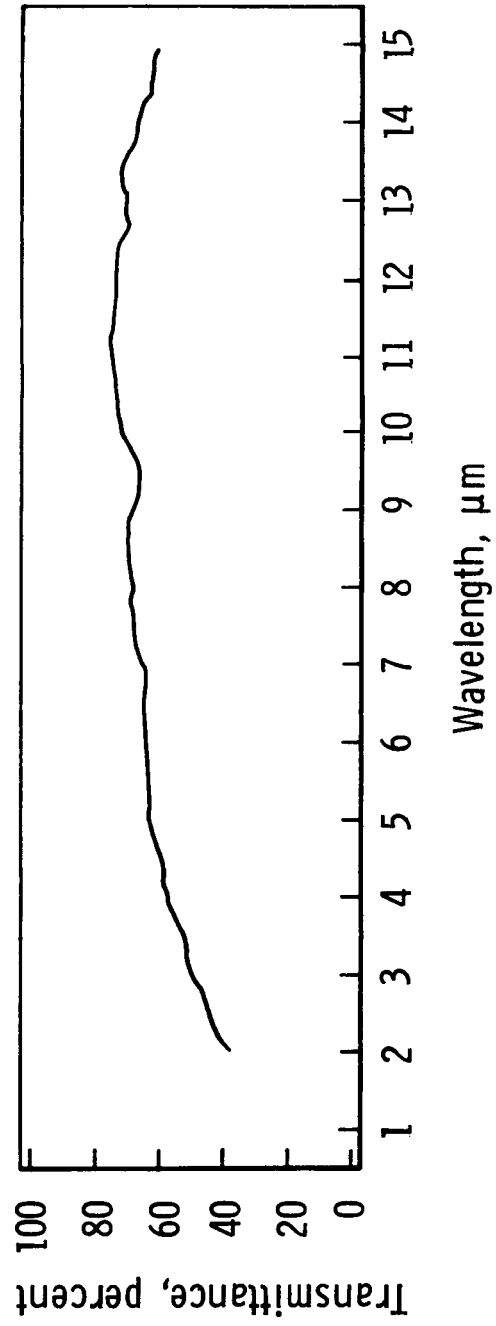


Fig. 7 IRE Spectrum--Post On-Orbit No. 1 (AEDC-1)

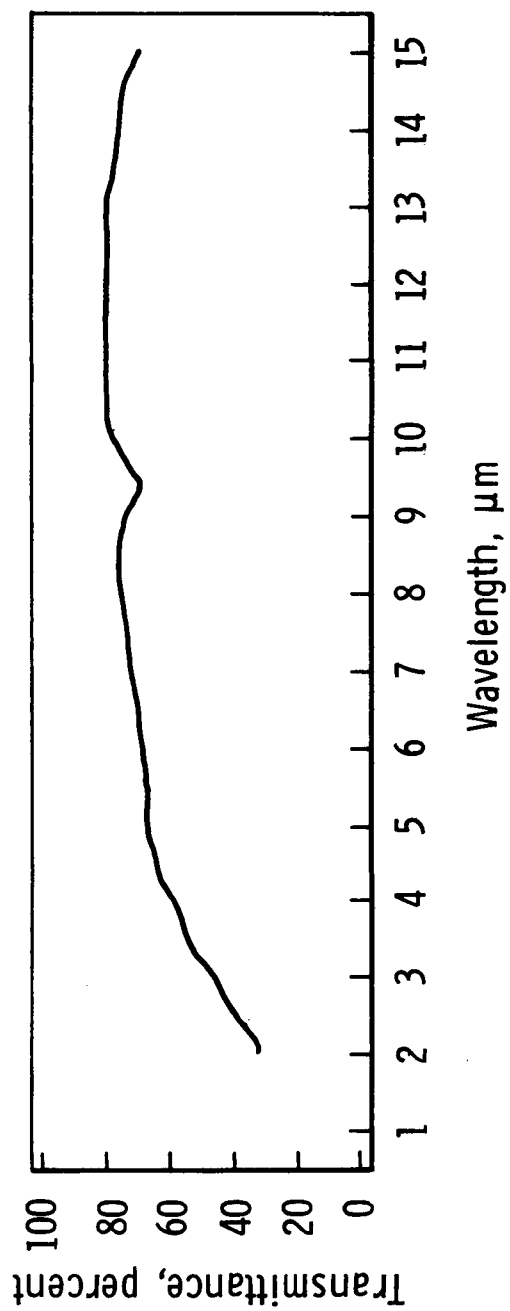


Fig. 8 IRE Spectrum--Post On-Orbit No. 1 (IR-8)

After the on-orbit #2 the MIRS spectra did not show a significant (doubling) increase in the DC-704 absorption bands thus it was concluded that the DC-704 deposition is a gradual continuous accumulation and not primarily occurring during the pumpdown or vent cycle. Also, during the on-orbit #2, IRE's IR-6 and -8 showed no increase in the 9.4 μm line strength, as determined by using neighboring transmission values as baselines, was observed.

Before the on-orbit #3 all the IRE's were cleaned with acetone and rinsed in ethanol, then scanned. The cleaning removed all evidence of DC-704 as is clear in Fig. 9. On-orbit #3 lasted 30 days and again the IRE's showed evidence of DC-704 of the same concentration as the scan of on-orbit #1 and #2 (total of 25 days), see Fig. 10. The plates located on the GPS, i.e., IR-6 and -8, also showed a slight transmission loss near 9.4 μm but this time the band was more indicative of DC-704, i.e., a square shaped transmission loss between 9 and 10 μm .

During a chamber inspection after the on-orbit #1 test, the mylar super-insulation behind the cryopanel was observed to have a haze, especially where it faced the diffusion pumps. A wipe sample was taken and the results are shown in Fig. 11. It is apparent that the combination of the aluminized mylar and the LN_2 wall separating the diffusion pumps from the test volume is an effective baffle. However, it is also apparent that the LN_2 cooled chevron baffles immediately above the pumps are not sufficient by themselves.

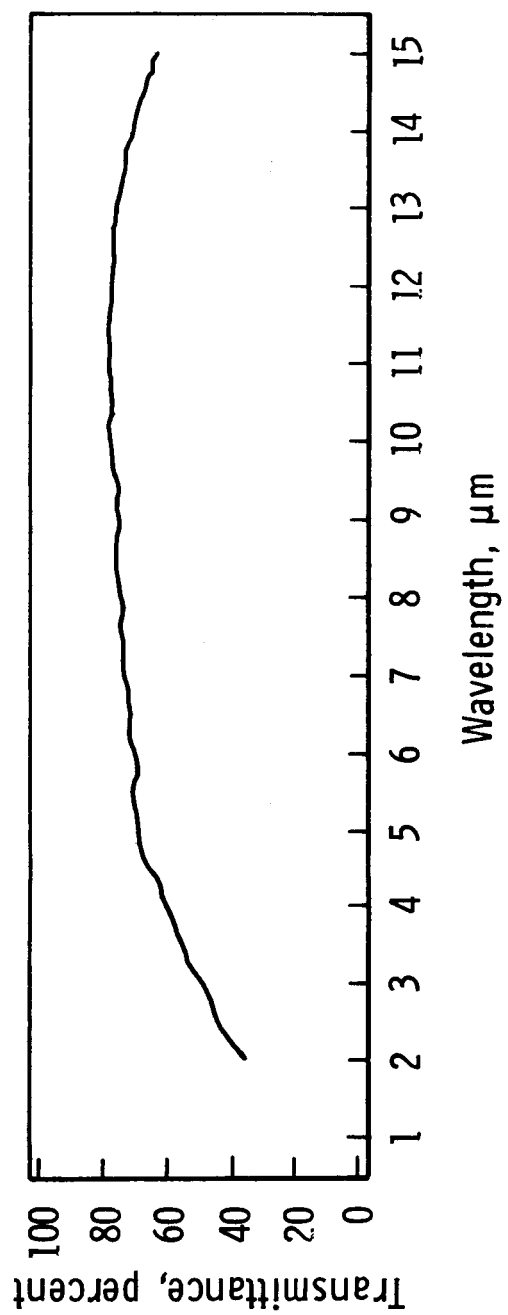


Fig. 9 IRE Spectrum--Prior to On-Orbit No. 3 (IR-8) after Cleaning

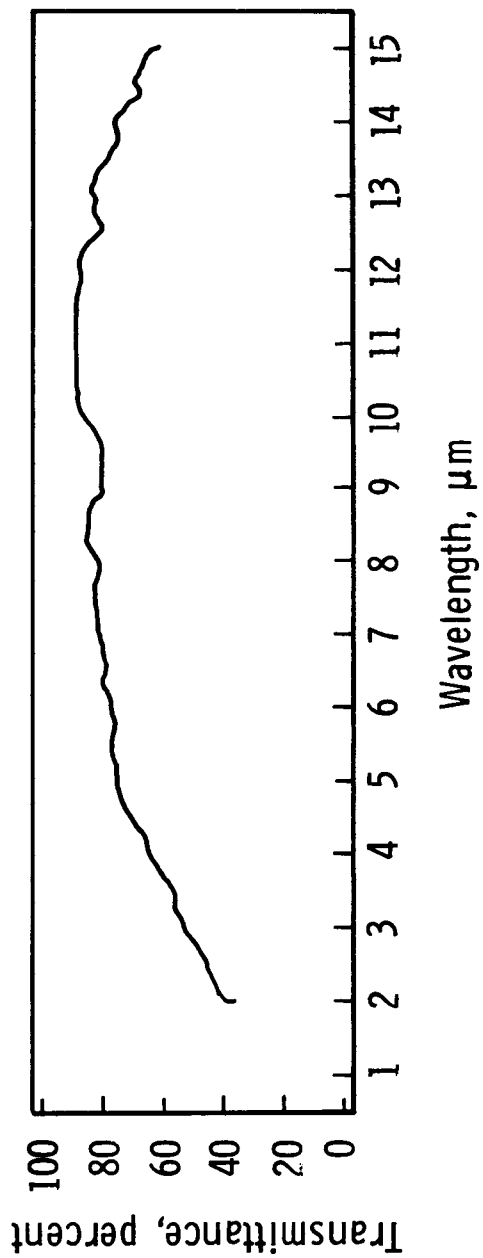


Fig. 10 IRE Spectrum--Post On-Orbit No. 3 (IR-10)

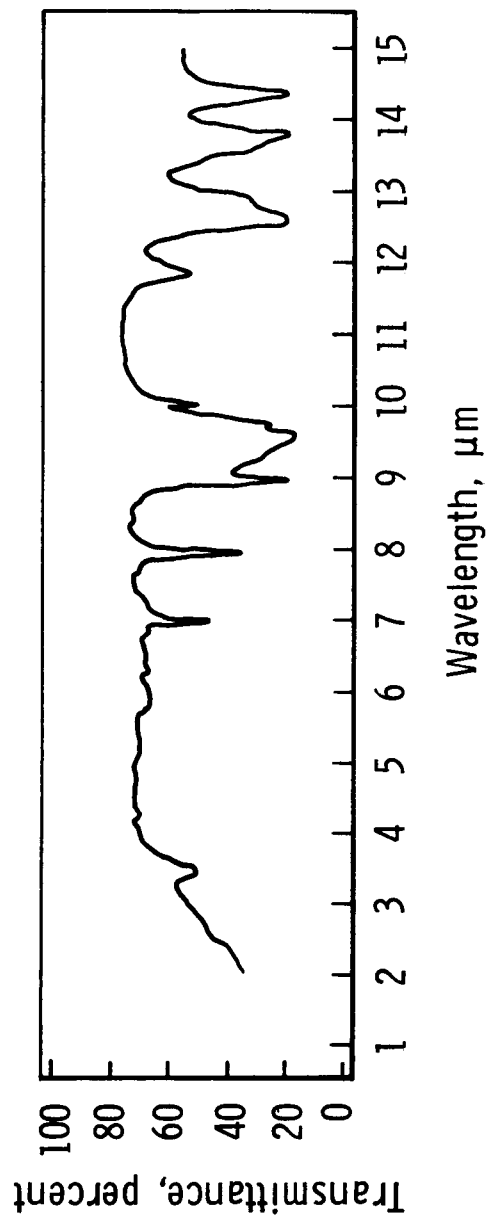


Fig. 11 Reference Spectrum--DC 704 Fluid from Al-Mylar Insulation

4.3 Quantitative Assessment

A quantitative assessment of DC-704 deposition required to produce the observed spectrum can be achieved with the aid of the quartz crystal microbalances (QCM's) results. The QCM's, temperature controlled to 290 ± 10 K and one uncontrolled ($T = 116$ K after equilibration with the Mark I environment) showed that a deposition took place during each period under vacuum; however, the deposits sublimed immediately following the return to atmospheric pressure and temperature (see Section 6.2). It is therefore believed the deposit was probably water and definitely not DC-704 since it would not have sublimed. Thus the minimum detectable mass deposition of the QCM may be used as an upper limit for DC-704 deposition, which, of course, assumes that the DC-704 background was uniform throughout the chamber, equally exposing the IRE and QCM crystals. The QCM's have a sensitivity of $1.7 \times 10^{-8} \text{ g/cm}^2\text{-Hz}$ and a change of 10 Hz is needed to positively indicate deposition. This implies an upper limit of $17 \times 10^{-8} \text{ g/cm}^2$ of DC-704 contamination or dividing by a density of 1.04 g/cm^3 a thickness of $16 \times 10^{-8} \text{ cm}$ (16 \AA). If it is assumed that the DC-704 was uniformly distributed across the plate, then the DC-704 layer on the IRE's could not have been, on the average, more than two molecular layers in thickness, since DC-704 is a phentaphenyl-trimethyl-trisiloxane molecule and the CH and SiO groups are the order of 3 \AA in characteristic size. For the size IRE's employed, the number of multiple reflections is 25 thus the loss of energy per reflection needed to yield a final loss of 5% is 0.25%. It must be left to the discretion of the thermal control engineer to determine if such a small

loss (0.0025) in reflectance at 9.4 μm (reflectance loss at other wavelengths is negligible) is detrimental to a thermal control surface. If it is, then the two molecular layers of DC-704 must be considered a contaminant, if it isn't, then the GPS (or any other hardware placed in the Mark I chamber) was completely free of contamination during the test.

5.0 WITNESS PLATES

5.1 Description

The witness plates were one-inch-diameter laminated wafers identical in form to the outer thermal control skin of the satellite. Two styles were employed, an aluminum plus 0.001 inch of Kapton over-coated with aluminum and a gold coated inconel over-coated with FEP Teflon. Seven witness plates were mounted on the satellite with double back tape (3M Y966) at strategic locations. The α/ϵ ratio of the plate was determined by measuring the reflectance at visible and near IR wavelength. A Rockwell specification of 0.002 for the Ag-FEP Teflon plates and 0.004 for the Al-Kapton plates was set as an acceptable upper limit for change in reflectance, for all wavelengths. This criterion is below the absolute accuracy limit on the Cary 90 and the Beckman DK-2A reflectometers employed to measure the reflectance, they are more near 0.01 to 0.02 accurate in reflectance measurement capability. Nevertheless the samples were scanned after the first test period.

5.2 Results

The reflectance of all the witness plates was found to be consistently within the measurement accuracy of the reflectometers. Thus it was concluded that the reflectance had not changed more than one

percent during a test period. Furthermore, after reviewing the MIRS results it was concluded that the reflectance measurements were unnecessary, since the IRE's which are twenty-five times more sensitive showed a very small level of contamination. The witness plates were still included on each test sequence but later stored for future reference in the event some concern arose regarding the thermal balance testing of the satellite. A typical infrared reflectance scan of an Al-Kapton and Ag-Teflon witness sample is shown in Figures 12 and 13, respectively, for illustration purposes.

6.0 QCM MEASUREMENTS

6.1 Instrument Description

During the entire GPS test, the Mark I chamber contained two quartz crystal microbalances which viewed the central volume of the chamber containing the satellite. These QCM's were of Jet Propulsion Laboratory origin, incorporating a 5 MHz crystal doublet (measuring and reference oscillators on the same $3/4 \times 1-1/2$ -inch crystal) with both crystals cut at $40^\circ 8'$ for cryogenic operation. See Chirivella³ for a more complete description of the JPL QCM's.

QCM #1 was strapped to the LN_2 -cooled frame of the fixed earth support tower and eventually reached a minimum temperature of 116 K; temperature variations were caused by changing solar simulator irradiance. QCM #2 was similarly mounted, but was wrapped with aluminized mylar and included a heater which maintained a crystal temperature of 284 K. (See Figure 4 for mounting arrangement of QCM's.)

³Chirivella, J. E., Hydrazine Engine Plume Contamination Mapping, AFRPL TR-75-16 (1975).

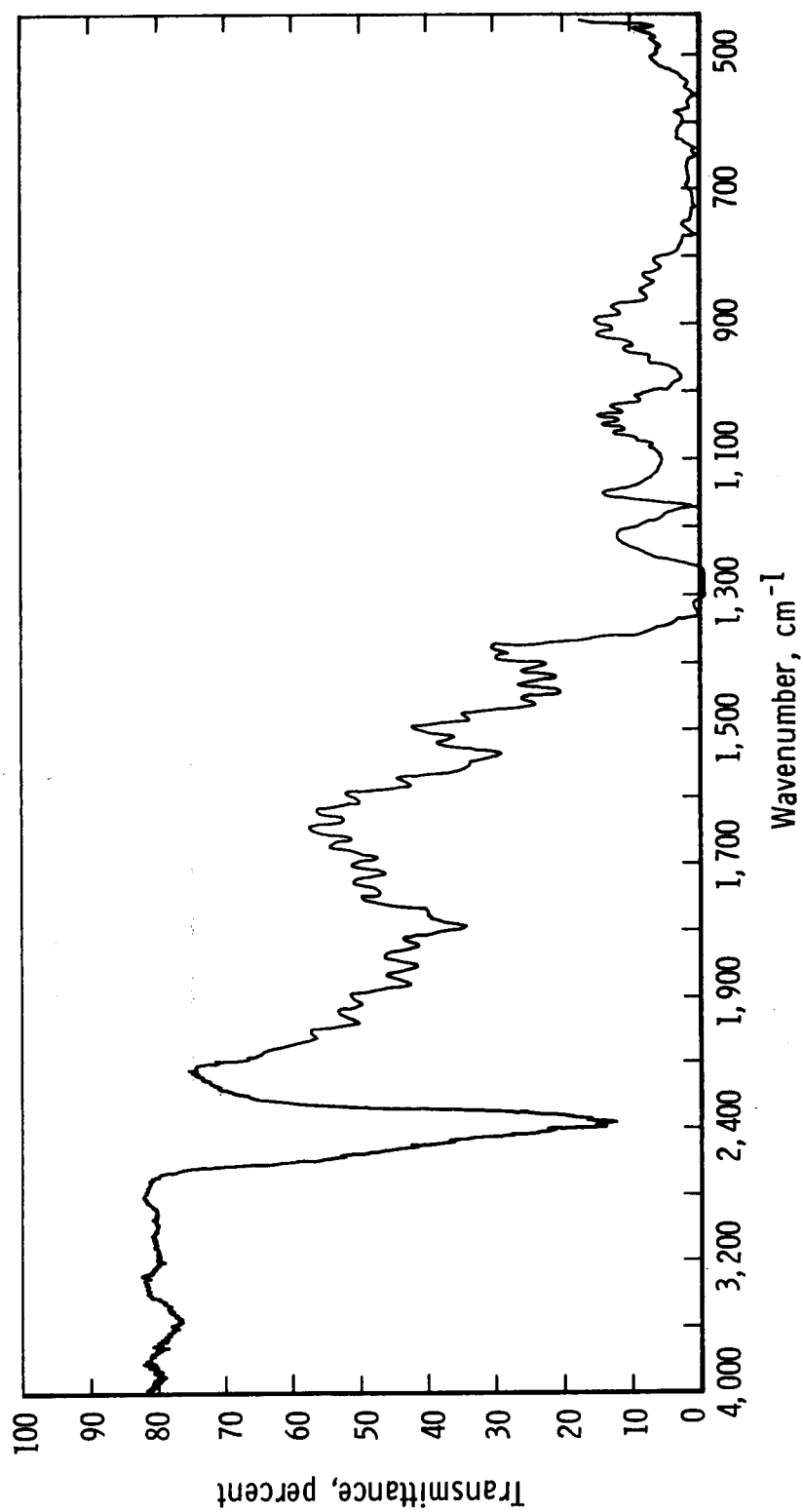


Fig. 12 Infrared Reflectance of Al-Kapton Witness P late

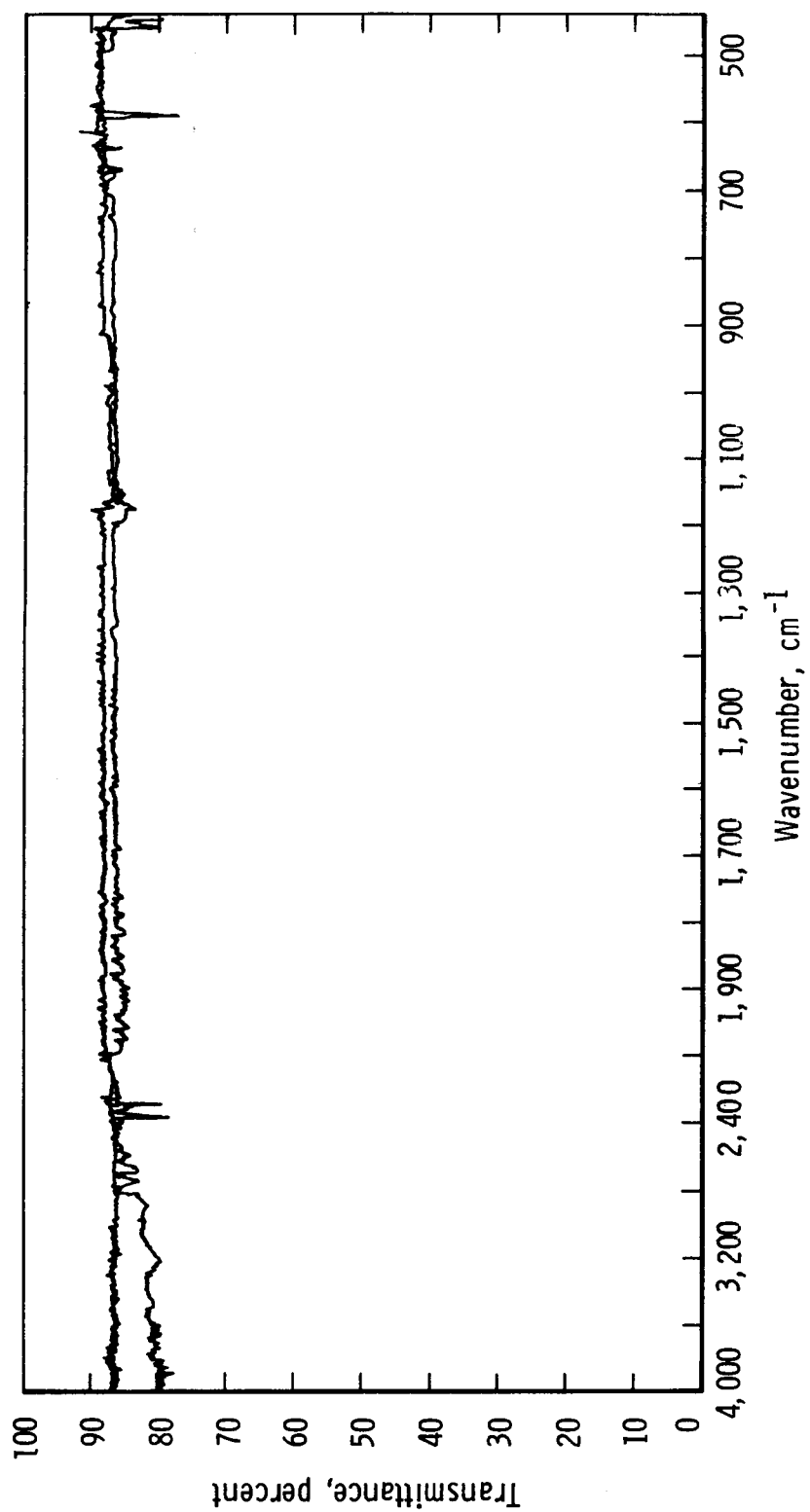


Fig. 13 Infrared Reflectance of Ag-FEP Teflon Witness Plate

6.2 Typical Data of Results

QCM output signals were recorded continuously via frequency-to-voltage converters and a dual pen strip chart, and hourly readings of a frequency counter were noted on the chart. Frequencies taken from the chart and counter are plotted along with crystal temperature in Figures 14 through 16. The actual frequency shown in the figures is a difference frequency between the measuring and reference oscillators on each QCM. As is clear in the figures the temperature controlled QCM (#2) showed a small change in difference frequency, the order of 70 Hz or a deposition of 1.2 μg in comparison to the cooled QCM (#1) which indicated a 4000 Hz maximum frequency change, or a deposition of 70 μg . The maximum deposition occurred during warmup of the chamber and is caused by a release of water vapor from portions of the chamber which warm at a higher rate than the QCM. The fact that the final frequencies after return to ambient conditions was within 10 Hz of the original frequencies and the QCM's indicated rapid loss of mass near 175 K (H_2O has a 10^{-5} torr vapor pressure at this temperature) it seems quite conclusive that the mass deposited on the QCM #1 was water vapor. Since the satellite is maintained at 300 K it was not subjected to contamination by water vapor.

7.0 SUMMARY

Through the usage of modern sensitive contamination measuring instruments a complete assessment of the contamination levels and types has been conducted for the AEDC Mark I space chamber. The general consensus is that the Mark I facility has a very low background contamination level (double layer level) of diffusion pump fluid. It must be

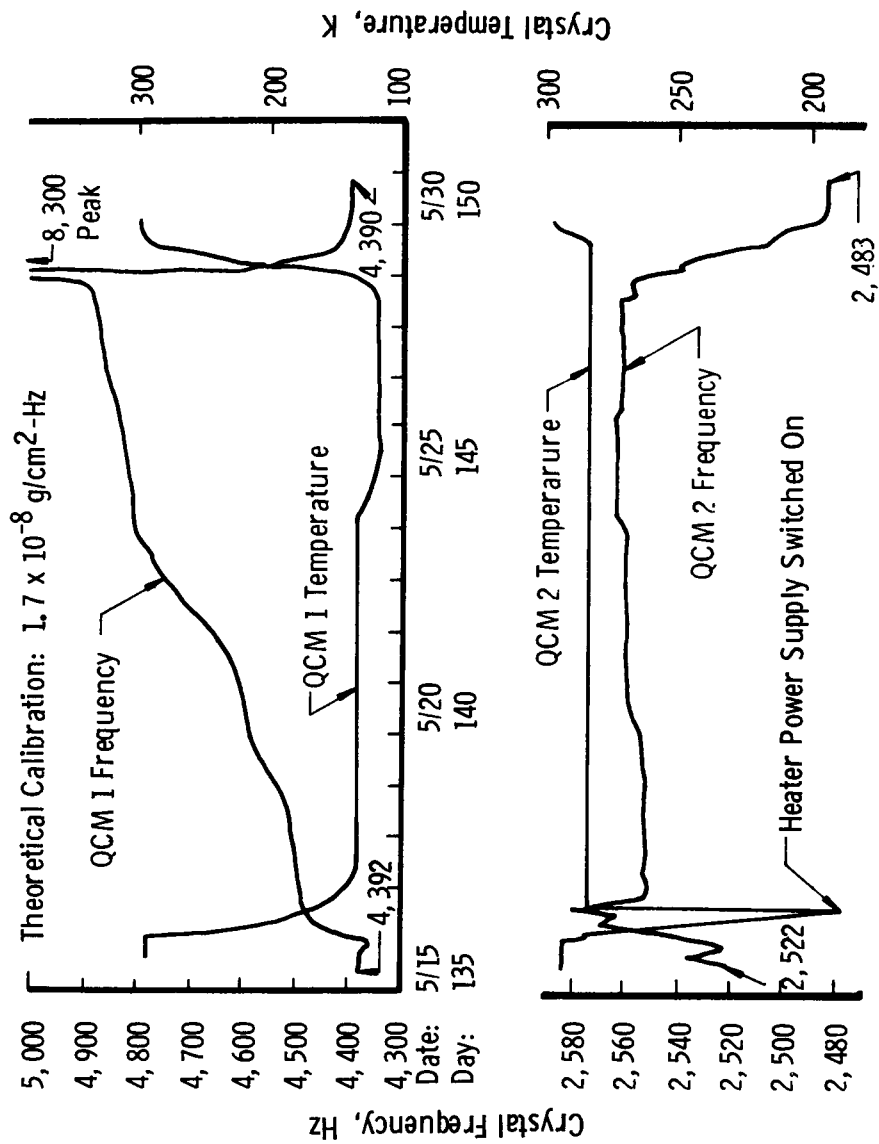


Fig. 14 QCM Measurements (On-Orbit No. 1)

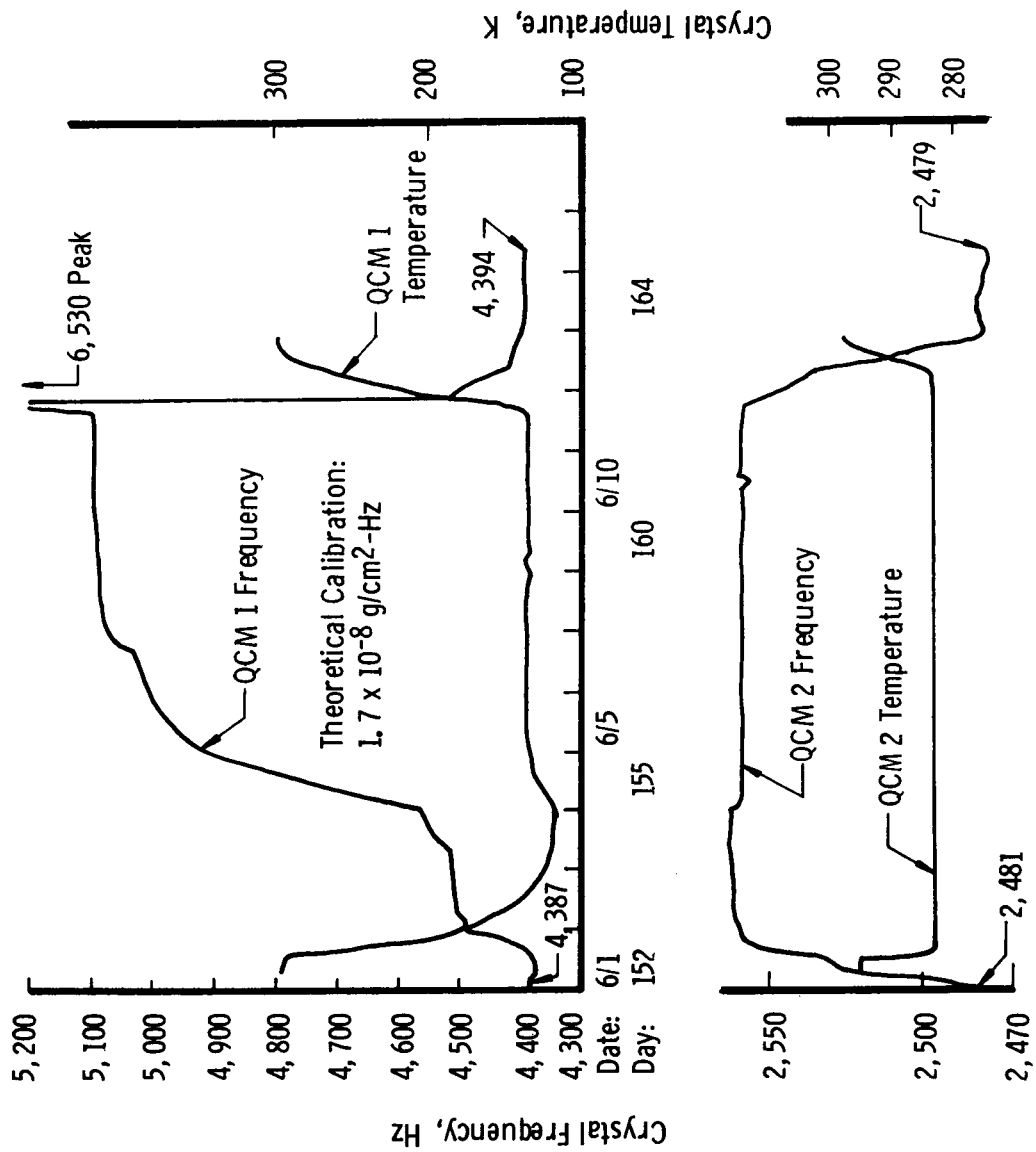


Fig. 15 QCM Measurements (On-Orbit No. 2)

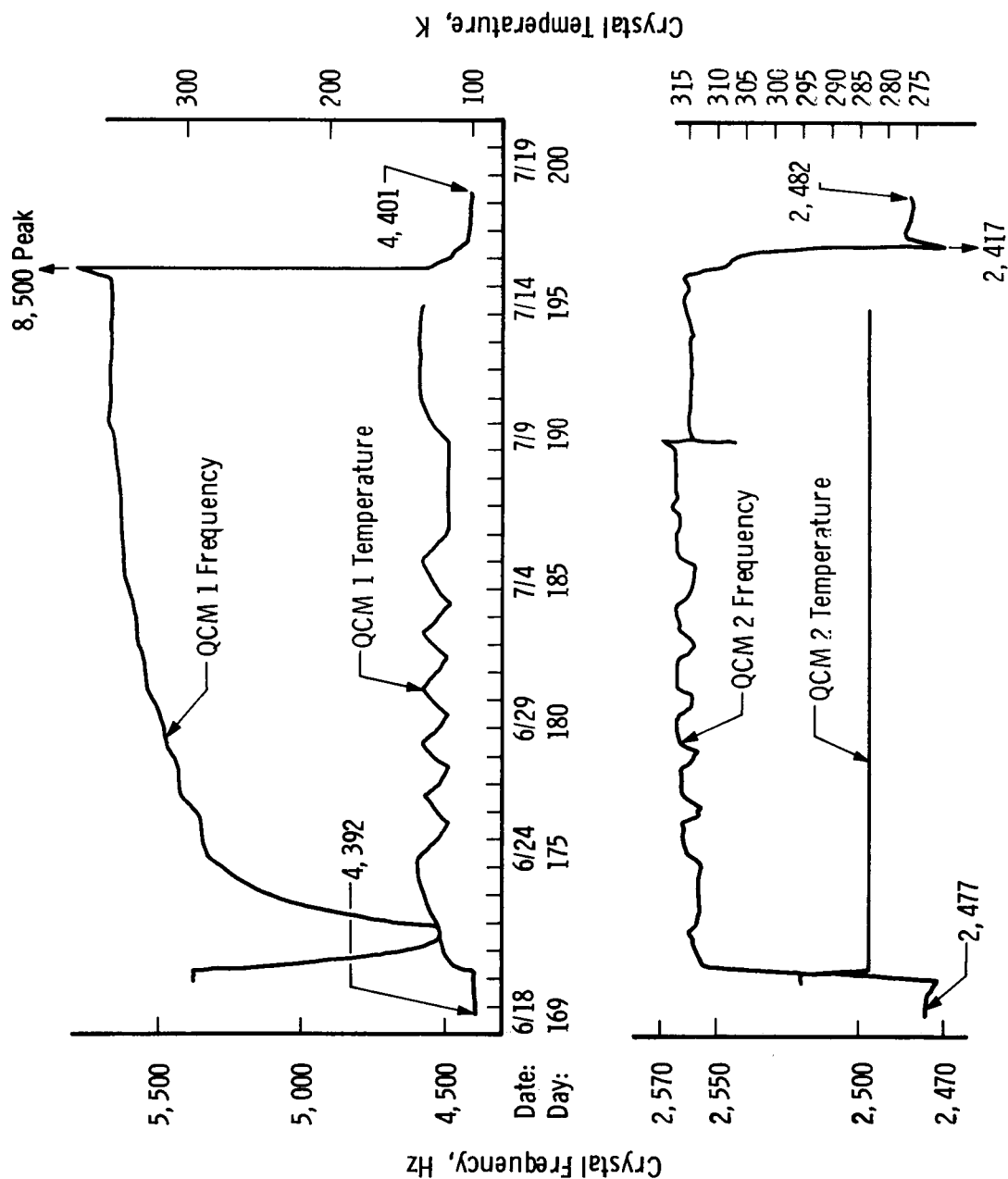


Fig. 16 QCM Measurements (On-Orbit No. 3)

decided by an expert thermal engineer if the level detected during the GPS test is detrimental or not. We feel, in general, that the background is acceptable in most cases and somewhat improvable if need be.

ACKNOWLEDGMENT

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REFERENCES

1. Harrick, N. J., Internal Reflection Spectroscopy, John Wiley & Sons, Inc. (1967).
2. ANSI/ASTM E573-76, Standard Recommended Practices for Internal Reflection Spectroscopy, American Society for Testing and Materials, Annual Book of Standards, Part 42.
3. Chirivella, J. E., Hydrazine Engine Plume Contamination Mapping, AFRPL TR-75-16 (1975).